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By

Ye. S. Borovik and N. G. Usikova

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PROPERTIES OF BLENDED BARIUM AND STRONTIUM FERRITES

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Barium and strontium ferrites belong to the hard ferromagnetic materials. But in comparison with the magnetic alloy magnico these ferrites possess lowered residual inductance B_r and less magnetic energy $(BH)_{max}$, although they do have increased coercive force H_c.

In the literature there are data on increasing magnetic energy in hard ferrites by additives of various oxides [1-3]. In this work the same aim of increasing the magnetic energy of ferrites is pursued and the results of research on the magnetic properties and several physical properties of blended hard ferrites of composition $Ba_{1-x}Sr_xO \cdot 6Fe_2O_3$ are presented.

Specimen Preparation and Measurement Technique

To prepare specimens of composition $Ba_{1-x}Sr_xO \cdot Fe_2O_3$ weight ratios of the powders $BaCO_3$, $SrCO_3$, and Fe_2O_3 were taken corresponding to the needed composition. The powder mixture (in the form of a liquid mass with water) was carefully ground for several hours in a mortar. Then the mixture was dried and roasted for five hours at 1100°C to form the blended ferrite. The slightly sintered ferrite powder was

ground in the mortar and from it were pressed specimens at a pressure of about 17 t/cm^2 without any binding material. The pressed intermediate products were sintered for an hour. Preliminary research showed that the optimum sintering regime lay between 1200-1300°. The specimens were 1 cm long cylinders with a cross-section of about 0.18 cm^2. The magnetic properties of the specimens were measured by the bridge method in fields up to 7000 oe at room temperature.

Results of Measurement

Figure 1 shows the dependence of the maximum magnetic energy $(BH)_{max}$ on composition for different sintering temperatures (curves 1-4). For a 1200° sintering temperature (curve 1) the magnetic properties of the blended ferrites turn out to be poorer than in pure ferrites. The curve $(BH)_{max}$ as a function of the composition has a minimum for the ferrite $Ba_{0.5}Sr_{0.5}O \cdot 6Fe_2O_3$. At this sintering temperature the size of the blended ferrite particles has evidently not yet attained the maximum size of single-domain particles.

For other sintering temperatures the properties of some blended ferrites are found to be better than in pure barium and strontium ferrites. It is evident from Fig. 1 that the curve of the dependence of $(BH)_{max}$ on composition has a maximum for $Ba_{0.7}Sr_{0.3}O \cdot 6Fe_2O_3$. The ferrite $Ba_{0.25}Sr_{0.75}O \cdot 6Fe_2O_3$ has poorer magnetic properties. The magnitude of the maximum magnetic energy $(BH)_{max}$ in $Ba_{0.7}Sr_{0.3}O \cdot 6Fe_2O_3$ specimens at sintering temperature 1230° attains a value of $1.45 \cdot 10^6$ gs · oe, i.e., almost 70% more than in pure barium ferrite and almost 50% more than in pure strontium ferrite. In sintering the specimens at 1300° the nature of the curve changes: the maximum on the curve of magnetic energy is displaced to ferrite $Ba_{0.5}Sr_{0.5}O \cdot 6Fe_2O_3$, but

this maximum is already substantially less pronounced and the absolute values of $(BH)_{max}$ for this sintering temperature are less for all the compositions than at 1230°.

The same figure shows the dependence of the residual intensity of magnetization B_r (curve 5) and of the coercive force $_IH_c$ (curve 6) on composition for the best sintering temperature 1230°. At this temperature the maximum B_r is observed in the same ferrite composition in which the minimum occurs on the curve of magnetic energy. A minimum is also observed for $Ba_{0.25}Sr_{0.75}O \cdot 6Fe_2O_3$, but the maximum and minimum on this curve are less sharply pronounced than on the magnetic energy curve.

The coercive force curve has one minimum for a composition of approximately $Ba_{0.5}Sr_{0.5}O \cdot 6Fe_2O_3$. Changes in the form of the curve of the dependence of B_r on composition connected with the sintering temperature are similar to changes for the curves of $(BH)_{max}$. The shape of the dependence curve of $_IH_c$ on composition is preserved unchanged for all the investigated sintering temperatures. The absolute values fall at sintering temperatures higher than 1200°.

The same curve nature was observed if the pure ferrites were sintered at optimum temperatures before preparing the blended ferrite and then the specimen of blended ferrite was obtained by re-sintering the pulverized and carefully mixed pure ferrite powders. The effects in this process were, however, much less clearly expressed.

To illustrate the temperature dependence of the investigated properties, Figure 2 shows the dependence curves of magnetic energy $(BH)_{max}$ on sintering temperature for differing compositions (curves 1-4) and residual intensity of magnetization B_r (curves 5-7).

The curves of $(BH)_{max}$ as a function of the sintering temperature

are in general similar for all compositions, but for a composition near the optimum ($Ba_{0.75}Sr_{0.25}O \cdot 6Fe_2O_3$) the most clearly expressed maximum is at a sintering temperature near 1230°. The curves of B_r for this ferrite composition have the same nature of temperature dependence with a maximum near 1230°. The temperature dependence of B_r for pure ferrites and the ferrite corresponding to composition $Ba_{0.25}Sr_{0.75}O \cdot 6Fe_2O_3$ are much less clearly expressed. The growth of B_r with the sintering temperature for ferrite $Ba_{0.5}Sr_{0.5}O \cdot 6Fe_2O_3$ deserves attention.

The curves of demagnetization for pure barium and strontium ferrites and for blended ferrites with extreme values of the properties ($Ba_{0.75}Sr_{0.25}O \cdot 6Fe_2O_3$ and $Ba_{0.25}Sr_{0.75}O \cdot 6Fe_2O_3$) are shown in Fig. 3.

Table 1 lists the values of the basic magnetic parameters of pure barium and strontium ferrites and of blended ferrites on magnetization in a field up to 7000 oe for the optimum sintering regime. For comparison the best data in the literature for isotropic ferrites [4] and an example for one of the anisotropic specimens [5] are also listed.

As is evident from Table 1, the properties of the composition near the optimum one are better than the properties of an ordinary isotropic ferrite (the magnitude of $(BH)_{max}$ is 75% greater and approaches the values of the anisotropic ferrite). The authors propose subsequently to investigate anisotropic blended ferrites.

Density and Physical Properties of the Specimens

An investigation of the results of measuring the properties of blended ferrites shows that in these specimens the physical properties also change. Figure 4 displays the curves of change of density of the

blended ferrites in relationship to sintering temperature. From a comparison of the curves it is evident that the $Ba_{0.75}Sr_{0.25}O \cdot 6Fe_2O_3$ specimen sinters best of all and the $Ba_{0.25}Sr_{0.75}O \cdot 6Fe_2O_3$ specimen, poorest of all, the sintering process finishing for the latter at 1230° and its density not changing at a subsequent increase in this temperature.

Table 2 lists the data on measuring microhardness and ultimate strength σ_{ult} during compression.

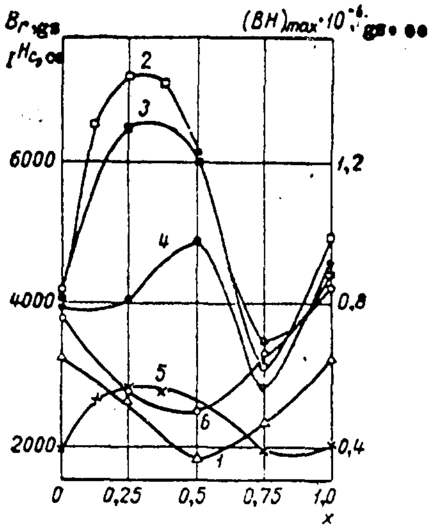

Fig. 1. Curves of the dependence of blended $Ba_{1-x}Sr_xO \cdot 6Fe_2O_3$ ferrites on composition for various sintering temperatures. $(BH)_{max}$ at 1) 1200; 2) 1230; 3) 1260; 4) 1300°C; 5) B_r at 1230°C; 6) $_IH_c$ at 1230°C.

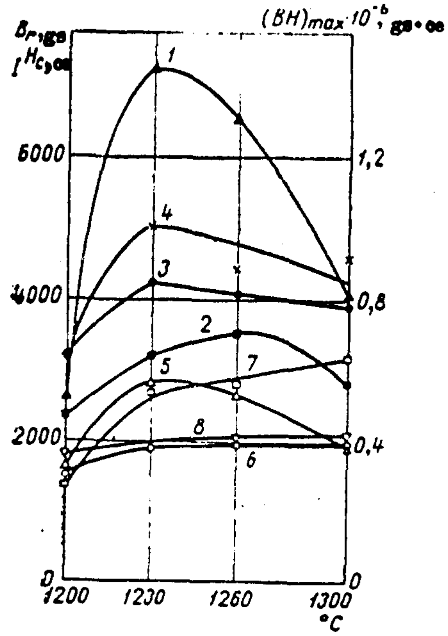

Fig. 2. Dependence of the properties of blended ferrites on sintering temperature for various compositions. $(BH)_{max}$ for 1) $Ba_{0.75}Sr_{0.25}O \cdot 6Fe_2O_3$; 2) $Ba_{0.25}Sr_{0.75}O \cdot 6Fe_2O_3$; 3) $BaO \cdot 6Fe_2O_3$; 4) $SrO \cdot 6Fe_2O_3$; B_r for 5) $Ba_{0.75}Sr_{0.25}O \cdot 6Fe_2O_3$; 6) $Ba_{0.25}Sr_{0.75}O \cdot 6Fe_2O_3$; 7) $Ba_{0.5}Sr_{0.5}O \cdot 6Fe_2O_3$, 8) $BaO \cdot 6Fe_2O_3$.

The ferrite with the optimum magnetic properties also has essentially the best physical properties, compared with pure ferrites. We may achieve an increase in the physical properties of pure ferrites by increasing the sintering temperature and using more active materials,

so that the listed figures for density and strength have only a relative significance. But for practical use it is essential that good physical properties be also found for composition $Ba_{0.75}Sr_{0.25}O \cdot$ $\cdot\ 6Fe_2O_3$ which has the best magnetic properties. It is curious to note very poor sinterability and low strength in $Ba_{0.25}Sr_{0.75}O \cdot 6Fe_2O_3$ ferrite.

Discussion of the Results

In the blended ferrite system $Ba_{1-x}Sr_xO \cdot 6Fe_2O_3$ a non-monotonic relationship between properties and composition is observed. Ferrite of composition $Ba_{0.75}Sr_{0.25}O \cdot 6Fe_2O_3$ at the optimum sintering temperature has better, and $Ba_{0.25}Sr_{0.75}O \cdot 6Fe_2O_3$ ferrite worse, properties than the pure components. Evidently the former's good properties are essentially caused by the better sinterability of the specimen of this composition. To illustrate this, the relationship of magnetic properties to composition with a correction for porosity was drawn. All the results of measuring magnetization were reduced to the single density value of 4.8 g/cm² by the formula $I_{corr} =$ $= I(\frac{4.8}{\rho})^{2/3}$. This method of introducing corrections is arbitrary to to a certain degree, but since the theoretical density of the blended ferrites is not known to us we must confine ourselves to it.

Figure 5 shows the curves of $(BH)_{max}$ and B_r reduced to a single density at the optimum sintering temperature 1230°. As may be seen, the curve maximum has substantially smoothed out and the minimum has become sharper. Thus, although the shape of the curves is partially cuased by the different sinterabilities of the differently composed specimens, still some other causes evidently lie at the bottom of the observed relationships. Research on the physical properties of such systems will be continued later on, but right now it is already clear

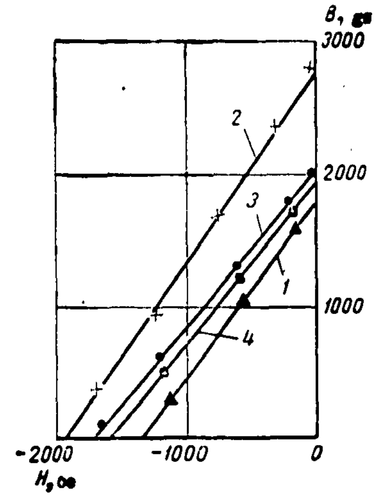

Fig. 3. Demagnetization curves for ferrites of differing composition (sintering temperature 1230°C). 1) $Ba_{0.25}Sr_{0.75}O \cdot 6Fe_2O_3$; 2) $Ba_{0.75}Sr_{0.25}O \cdot 6Fe_2O_3$; 3) $SrO \cdot 6Fe_2O_3$; 4) $BaO \cdot 6Fe_2O_3$.

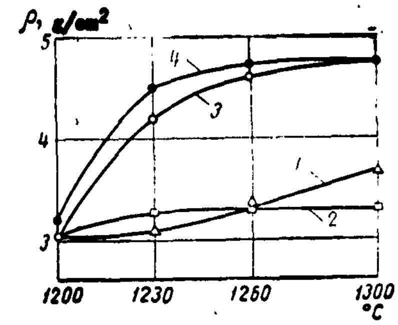

Fig. 4. Dependence of density ρ on sintering temperature in ferrites of differing composition. 1) $SrO \cdot 6Fe_2O_3$; 2) $Ba_{0.25}Sr_{0.75}O \cdot 6Fe_2O_3$; 3) $Ba_{0.5}Sr_{0.5}O \cdot 6Fe_2O_3$; 4) $Ba_{0.75}Sr_{0.25}O \cdot 6Fe_2O_3$.

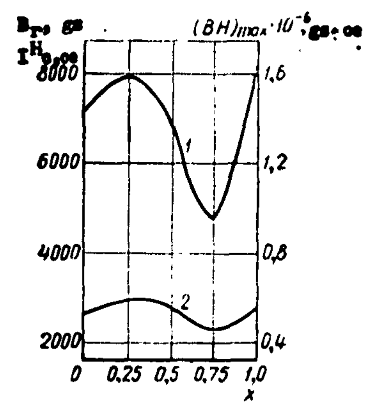

Fig. 5. Dependence of properties of blended $Ba_{1-x}Sr_xO \cdot 6Fe_2O_3$ ferrites on composition, adjusted to the practical density of barium ferrite, 4.8 g/cm² (sintering temperature 1230°C). 1) $(BH)_{max}$; 2) B_r.

TABLE 1

Composition	B_r, gs	$_IH_c$, oe	$(BH)_{max} \times 10^{-6}$, gs·oe	Density, g/cm²	T_{sint}, °C
$BaO \cdot 6Fe_2O_3$	1950	3750	0,84	3,02	1230
$SrO \cdot 6Fe_2O_3$	2050	4200	1	3,08	1230
$Ba_{0.75}Sr_{0.25}O \cdot 6Fe_2O_3$	2800	2700	1,45	4,5	1230
$Ba_{0.25}Sr_{0.75}O \cdot 6Fe_2O_3$	1900	3200	0,71	3,25	1260
$BaO \cdot 6Fe_2O_3$ Isotropic	2050	2420	0,85	4,8	—
$BaO \cdot 6Fe_2O_3$ Anisotropic	3000	1800	1,8	4,8	1300

TABLE 2

Composition	Microhardness No.	σ_{ult}, kg/cm²
$BaO \cdot 6Fe_2O_3$	96,5	2000
$SrO \cdot 6Fe_2O_3$	106,3	1770
$Ba_{0.25}Sr_{0.75}O \cdot 6Fe_2O_3$	41,2	1770
$Ba_{0.5}Sr_{0.5}O \cdot 6Fe_2O_3$	885	2800
$Ba_{0.75}Sr_{0.25}O \cdot 6Fe_2O_3$	600	3500

that blended ferrite $Ba_{0.7}Sr_{0.3}O \cdot 6Fe_2O_3$ is a better magnetic material than pure barium and strontium ferrites.

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A. M. Gor'kiy, State University of Khar'kov

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